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PRODUCTION OF LARGE-SIZE ANTIFRICTION BEARINGS AT THE MOSCOW FIRST STATE BEARING PLANT

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/The table and figures referred to are appended./

To restore ferrous metallurgy plants /after World War II/, the bearing industry had to organize, in a short time the output of antifriction bearings up to 1,200 millimeters in diameter for rolling mills. In addition, other branches of machine building are beginning to require large-size bearings.

For these reasons, the Moscow First State Bearing Plant, in particular, had to solve the whole complex of problems connected with the production of large-size bearings (materials, hot and cold working of parts, hardening, and casehardening).

Material

Ordinary types of antifriction bearings are made of ShKh15 steel, and their heat treatment does not present any special difficulties. When the size and, consequently, the cross section of bearings is increased, difficulties arise in the hardening process.

To obtain good hardenability of heavy parts made of ShKh15 steel, the hardening temperature must be raised. This higher temperature produces a poor metal structure, creates hardening stresses and fissures, and increases the percentage of residual austenite in the steel. Different combinations of temperature and heating and cooling methods do not always produce satisfactory results, especially in the hardening of parts with complex forms. The simplest solution of this problem is to increase manganese content in ball-bearing steel used for making large parts. The presence of one percent manganese in ShKh15 steel gives good hardenability and high, evenly distributed hardness on the surface of large-cross-section parts when they are quenched in oil.

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Steel with an increased manganese and silicon content is listed in GOST (State All-Union Standard) 801-47 as Type-ShKh15SG steel.

Bearings made of hard steel do not stand up under high specific loads accompanied by impact loads. Observations have shown that dynamic loads have a considerable effect on the life of bearings in rolling mills. Rings made of hard steel rapidly break down, with the characteristic distribution of open fissures along the roller track.

Bearings made of low-carbon alloy steel and then casehardened are the most durable, since the casehardened bearings stand up better under the dynamic loads which inevitably arise in the operation of rolling mills.

For taper multirow bearings used in rolling mills under especially severe operating conditions, 12Kh2N4A and 20Kh2N4A chrome-nickel casehardening steels are used.

Hot Working and Heat Treatment of Forgings

The physical and mechanical properties of forgings and rings depend on the structure which forms during hot working of ingots and rolled stock. This is mainly applicable to ShKh15 and ShKh15SG high-carbon steels ard, to a lesser extent, to casehardening steels. As a rule, large-size bearing steel rolled stock arrives from the metallurgical plant after having been reduced 1.5-3.5 times. As a result of insufficient reduction of the center of the blank, the metal may retain, to a great extent, the structure of a casting, that is, it may have porosity and other defects. For this reason, ring forgings should not be made from rolled stock if the ratio of the height of the forging to the size of the stock is less than 2.1. Table 1 gives the weight of forgings and the dimensions of the rolled stock from which these forgings should be made. The minimum weight of the forging corresponds to a 2:1 ratio of the height of the forging to the size of the square stock, and the maximum weight corresponds to a ratio of 3:1.

Making large forgings by smith forging involves leaving large machining allowances, sometimes as much as several dozen millimeters. To reduce allowances for lathe machining, the method of hot rolling the rings on forging rolls is used (Figure 1).

The forging temperature of bearing ste is very important and is selected according to the forging method used. Thus, for smith forging on a hammer forge, when the forging process lasts a long time, the blank may be heated to 1,100 degrees centigrade, so that the forging process is completed at a temperature of 850-800 degrees centigrade. For drop forging, the temperature of preheating should not exceed 1,050 degrees centigrade.

Rolling bearing rings on forging rolls takes 45-90 seconds, and the blank has virtually no time to cool off. Therefore, preheating for rolling should not exceed 950 degrees centigrade.

The temperatures at the beginning and end of the forging process should be well coordinated. It is important to assure a correct cooling process after forging, with the following two goals in mind: (a) to prevent the formation of carbide crystals in the structure of the steel; and (b) to prevent the formation of cracks in the steel. The first requires rapid cooling of the forging to a temperature of 700-600 degrees centigrade; the second requires slow cooling from 500 degrees centigrade down. Precise fulfillment of these conditions may be achieved on a conveyer which carries the forgings for a fixed length of time while they are cooled either by compressed air or a water spray (mist), after which they fall into a box where final cooling takes place at a slower rate.

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Annealing

Forgings made of ball-bearing steel are annealed at a temperature of 800 degrees centigrade. Forgings of chrome-nickel steel are normalized at 900-940 degrees centigrade by air cooling and then annealed at 650-670 degrees centigrade.

Lathe Machining of Rings

The special problem arising in the turning of large-size ring forgings (800-1,000 millimeters) is that the unequal distribution of machining allowance, owing to out-of-round rings, varying wall thickness, hollows, and forging faults, makes necessary constant resetting of the ring on the machine tool. Lathe turning of forgings consists of roughing and finishing on chucking lathes or on vertical lathes.

The forgings were set up and fastened in four-jaw chucks by hand. Fastening in the chuck caused considerable elastic deformation, and, as a result, the outer ring was usually out-of-round about 0.8 millimeter and the inner ring, about 0.4 millimeter. In the process of lathe machining without using a coolant, the ring was heated to 70-80 degrees centigrade, and its diameter increased 0.008 millimeter per 1,000 millimeters for every degree rise in temperature.

Heat Treatment

Casehardening the surface of steel with carbon, a method long used in our technology, is widely known and practiced. However, deep carburizing (up to 10 millimeters) is not a common practice. Figure 2 gives the curve of hardness distribution by depth of the casehardened layer of 12Kh2N4A steel for various hardening temperatures and the curve showing changes in the carbon content according to the depth of the layer, as shown by chemical analysis. Casehardening is carried out with a solid carburizer. According to the carbon content curve, the [maximum] depth of casehardening is 7 millimeters, which corresponds to a Rockwell C Scale hardness of 44.

There is some further decrease in hardness owing to the annealing process and to poor saturation of the deeper layers with carbon. The degree of carbon saturation of the steel surface is reasonably high (up to 2 percent) and decreases sharply the deeper one penetrates. In layers with a high carbon content (more than 0.7 percent), raising the hardening temperature causes a marked decrease in hardness, owing to the formation of a considerable amount of austenite.

This data makes it possible to outline machining methods, taking into account the behavior of the surface and underlayers of casehardened steel, which become the working surface after the allowance is removed by grinding.

Let us compare three methods of carburization: casehardening with a solid carburizer, gas casehardening, and liquid cyaniding. Specimens of 12KhN3A steel were carburized for 160 hours at a temperature of 930 degrees centigrade. The following conclusions were reached on the basis of this test

1. Casehardening with a solid carburizer is the most stable and most controllable process of carburization, but it produces a great quantity of surplus carbide on the surface and to a certain depth beneath the surface. These carbides can be reduced by reducing the amount of catalyst in the carburizer.

2. Gas casehardening makes it possible to regulate the process by additional soaking at the casehardening temperature, which brings about diffusion of the carbon from the surface inwards.

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3. The degree of carbon saturation of the metal in high-temperature cyaniding is the lowest of the three methods and depends on the composition of the bath and the length of immersion. In a fresh bath, the carbon saturation curve of the steel corresponds to the curve of a solid carburizer. However, the carbon content of the surface never exceeds 1.1 to 1.15 percent. High-temperature cyaniding is of little practical importance owing to the low productivity of the baths.

Hardening and Casehardening Practice

In 1941, an experimental group of bearings were heat treated at the Izhorskiy [probably Izhmorskoye] Plant, and some peculiarities of their casehardening and hardening were brought out in these tests (shrinkage during heat treatment, and a tendency to great deformation and saturation of the surface with carbides, making it necessary to remove this layer by grinding).

The heat treatment of large-size rings is made up of the following operations: (a) casehardening with a solid carburizer mixed with coke and containing a relatively small amount of catalyst; (b) quenching the rings in oil immediately after removal from the casehardening box; (c) high-temperature tempering after they are fully air cooled; (d) quenching the rings in oil until they are fully cooled; and (e) two low-temperature (180 degrees centigrade) temperings, with a 24-hour interval between the temperings.

After casehardening, hardening, and tempering, the amount of shrinkage is measured.

For casehardening, 100-kilowatt shaft furnaces with two zones were built. A protracted (up to 200 hours) casehardening process was planned for, and for this reason, much attention was given to the packing of rings in the pots. A set of rings consisting of two inner and three outer rings was loaded into a pot 900 millimeters high. In loading the pot, special care was taken to fit the lower rings firmly against the crosspiece so that they would not undergo deformation under their own weight. Equal vertical gaps between the inner and outer rings were obtained by using packing strips.

The carburizer consisted of coal coke and a bonding mixture in a ratio of 1:1. The particles of carburizer were 5-12 millimeters in size. The casehardening mixture consisted of 70 percent used and 30 percent fresh carburizer. Special test specimens were packed in the pots along with the rings.

The pot was insulated on top with two layers of sheet asbestos, and the seam was covered with fire clay and water glass. Coal dust was sprinkled between the layers of asbestos. The pot was covered with an iron lid, and the edge of the lid and the pot were insulated with a thin sheet of asbestos and carefully coated with fire clay and water glass. This system of insulation protected the carburizer from burning out when held at a temperature of 940 degrees centigrade for long periods of time.

Depth of casehardening, depending on the diameter and thickness of the rings, was from 6 to 1[illegible] millimeters. After casehardening, the pot was removed from the furnace and placed in a special pit. After the lid and the depth-of-casehardening specimen were removed, the top layer of asbestos and coal was cleared off and a crane was used to lift out the crosspiece and rings and load them into an oil tank. After 4-6 minutes, the rings cooled to 250-300 degrees centigrade in the oil and then cooled further in the air. After washing in a boiling soda solution, the rings were loaded in a furnace for high-temperature tempering. Tempering temperature was 650 degrees centigrade and lasted 6-7 hours. The purpose of the high-temperature tempering was to break down the austenite particles formed in the casehardened layer during the first quenching.

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(The process of casehardening large-size rings in gas casehardening shaft furnaces has now been perfected.)

For hardening, the ring on the crosspiece is placed in an electric shaft furnace at a temperature of 650-700 degrees centigrade and preheated for 30-50 minutes, after which the furnace is turned on higher and heated to the hardening temperature of 790-800 degrees centigrade. Total heating time is 1.5-3 hours. The specimens are hardened along with the rings, so that the quality of casehardening and of hardening can be determined from them. In the oil tank, the rings cool to 80 degrees centigrade and then cool in air to room temperature.

To increase hardenability and obtain a Rockwell C Scale hardness of 35-40 in the core of the rings, a ring-shaped device was placed in the tank to circulate the oil. This device was a hydraulic pump which forced the oil out of the tank into pipes welded to the tank at an angle. This stream of oil creates circulation currents in the oil, moving in the opposite direction to the ring on the crosspiece.

Tempering was carried out at 170-180 degrees centigrade after the rings were cooled to room temperature, and the process was repeated after 24 hours. The rings were tempered from 6-8 hours in 30-kilowatt electric shaft furnaces, with forced circulation of air provided by a blower.

Hardening in Dies

In the casehardening and hardening of large-size rings, shrinkage of 3-4 millimeters, measured on the diameter, takes place. The extent of this shrinkage depends on depth of casehardening, diameter, cross section, and other factors.

Shrinkage is greater on the inner diameter than on the outer. This is taken into account, and in lathe machining, all of the allowance for grinding is left on the outer diameter. On the inner diameter, the allowance forms after casehardening and hardening, owing to shrinkage. The unpredictability of changes in dimensions and warping make it necessary to retain large allowances for the grinding of rings (3-4 millimeters), which reduces the productivity of equipment and raises the production cost of large-size rings. Allowances of tapered outer rings are lowered by reducing out-of-round and eliminating shrinkage by hardening the rings in special divided dies (Figure 3). The heated ring is mounted on the lower half of the die, and the upper half of the die is fitted to the lower half and made fast with a key. The die and ring are lowered into an oil tank. As it cools, the ring tightens on the die, and the shape of the die prevents out-of-round and limits shrinkage.

The use of dies eliminates large grinding allowances, decreases the depth of the casehardened layer, and makes heat treatment more profitable. The casehardened layer in the finished ring should be 2.5-3 millimeters thick.

For tests in hardening large-size rings in free dies, outer rings were made for bearing No 377/560. The outer diameter of the ring was 825 millimeters; the diameter of the roller track was 773 millimeters.

The test was conducted with three variants. Four rings were made according to the working blueprints, which specified that 80 percent of the total grinding allowance be given to the outer diameter and 20 percent to the inner, and two rings were made according to a special sketch with the same allowance (50 percent) for the external and internal diameters.

Variant A

Two rings were hardened in the usual way on a crosspiece (with free shrinkage and nothing to prevent the rings from getting out-of-round).

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Variant B

Two rings were hardened in dies which permitted free shrinkage of the rings but prevented them from getting out-of-round.

Variant C

The rings were hardened in dies designed to prevent any shrinkage or out-of-round.

The dies were made 1.7 millimeters smaller than the rings. The rings hardened according to variant B did not shrink onto the die sufficiently and became slightly out-of-round. The rings hardened according to variant C shrank 1.7 millimeters and took on the actual dimensions of the die.

Results of the test showed that in every instance, the over-all allowance (of the outer and inner diameters) for grinding increased sharply as a result of the increase in volume of the steel during heat treatment.

By using dies, out-of-round can be eliminated and the rings hardened to a given size. Allowances can be reduced not only by improving the design and eliminating shrinkage but also by taking into account the increase in volume of the steel, brought about by the absorption of carbon during the casehardening process.

A special press machine is now being built for hardening rings in dies.

Control of the Heat-Treatment Process

Before heat treatment, the inner diameter, outer diameter, and roller track of every ring is measured and the dimensions recorded on a special form that goes with the ring. From this data, changes in dimensions (shrinkage) and deformation (out-of-round) can be noted, and the remaining allowance for grinding to the blueprint dimensions can be defined.

This data is then entered on a hardness diagram for the cross section of the casehardened layer, based on analysis of the specimen which went through the entire heat-treatment cycle with the rings. The diagram gives all the necessary characteristics for each ring of the given bearing (Figure 4) as follows:

1. The intersection of the hardness curve with the horizontal, corresponding to a Rockwell C Scale hardness of 44, gives an average depth of casehardening of 10 millimeters.

2. The intersection of the hardness curve with the horizontal, corresponding to a Rockwell C Scale hardness of 58, shows that the casehardened layer with a hardness that meets the specifications is at a depth of 6 millimeters.

3. Vertical lines a-a and b-b indicate the thickness of the layer that will be removed by grinding; in one place this layer is 1.4 millimeters thick, in another, it is 2.7 millimeters thick. (The difference is accounted for by out-of-round of the ring, equal to 1.3 millimeters.) The section of the curve between the vertical lines indicates the hardness of the working surface of the ring, so that in spite of the difference in thickness of the layer removed by grinding, the hardness for the entire surface is 63 Rockwell C Scale.

From this graph, one can also determine the average thickness of the casehardened layer that has a Rockwell C Scale hardness of more than 58, and also the structure on the rolling surface of the finished ring.

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Grinding of the Rings

If hardening dies are not used, the distribution of allowance between the inner and outer diameters after lathe machining will be unequal, owing to shrinkage during heat treatment. Thus, for a ring with a diameter of 800 millimeters, the allowance on the outer diameter after lathe machining is 5-7 millimeters, and the allowance on the inner diameter is 0.5 to one millimeter. After casehardening and hardening, the allowance on both the inner and outer diameters is approximately the same, 3-5 millimeters.

The wheel is ground in two operations. Rough grinding takes off up to two thirds of the total allowance and differences in allowance owing to out-of-round, after which the ring is tempered at low temperature to remove stresses. Finish grinding brings the ring to the dimensions indicated on the blueprints.

Rough grinding is very exacting. The necessity of removing a large allowance makes it seem desirable to speed up the grinding process, but at the same time, it must be kept in mind that the surface of the ring is supersaturated with carbide, contains a great quantity of austenite, and as a result, is highly sensitive to stresses, which, in turn, are very apt to form grinding fissures. These fissures may be removed along with the layer of metal, or they may be deepened by subsequent grinding. Therefore, grinding fissures must not be permitted.

Rough grinding of the face was carried out on a surface grinding machine with a round table; and rough grinding of the inner and outer diameters was carried out on face grinding machines or on internal grinding machines of the Wotan type. The parts were set up on face plates fitted with special jaws, in which ground supports for the faces were mounted carefully.

The ring was clamped on the face; for radial centering, the ring was set by spacing bolts in the jaws. The grinding wheels were 400, 300, and 200 millimeters in diameter (E46SMB and E46MZK wheels) and were as wide as the roller track. At normal grinding speeds, the grinding wheels showed good stability and productivity, and there were not fissures or burns on the ground surfaces.

Rough grinding on the Wotan grinder was carried out as follows: Rotation speed of the ring was 45-70 meters per minute; rotation speed of the grinding wheel was 22-26 meters per second; and speed of longitudinal travel of the table was 2-3 meters per minute.

Feed of the grinding wheel for two revolutions of the table was 0.0015-0.0025 millimeter.

Wear of the grinding wheel in removing a one-millimeter allowance from the surface being ground, including dressing, was 20 millimeters. Accuracy of rough grinding (plus 0.2-0.3 millimeter) was sufficient.

Finish grinding of the outer and inner diameters of the rings was done on a Wotan grinding machine or on the universal rotary (karusel'niy) grinding machine made by the Khar'kov Machine-Tool Building Plant imeni Molotov. Radial pulsation was controlled by means of an indicator in the support.

The high degree of accuracy of set-up on the face plate in the machine made by the Khar'kov Machine-Tool Building Plant produced a ring in which out-of-round after finish grinding did not exceed 0.012 millimeter for a ring about one meter in diameter.

Out of round, nonperpendicularity of the roller track, with respect to face of the ring, or eccentricity of the roller track, with respect to the outer or inner diameter was not permitted to be greater than 0.06 millimeter; and skew of

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the roller track, no greater than plus or minus 0.0005 millimeter. For finish grinding, E90MZK grinding wheels were used. Grinding speeds for finish grinding were equal to the lower figures given above for rough grinding. When grinding the roller track of the inner ring by the notching method, the feed is reduced to 0.005-0.001 millimeter per revolution.

The most difficult problem in carrying out these operations was to eliminate vibration created by insufficient rigidity of the spindle holding the grindstone.

To obtain a more accurate angle on the roller track, lapping was used.

It was noted that a temperature increase of 10 degrees centigrade increased the diameter of an 800-1,030-millimeter-diameter ring by approximately 0.08 millimeter.

Assembly of Bearings

A description of the assembly of the most complex four-row taper roller bearing follows. The rings and rollers are sorted by size into bearing sets on the basis of the control slips. Then, the peripheral diameters of the center holes in the cage shield for the spacer are calculated for the set of rings, and the rollers are selected. While the shield for the inner ring is being prepared, the rollers and cage are assembled. The head of the spacer is electrically welded after assembly. During the welding operation, the bearing should be protected from falling metal particles (sparks) by carefully shielding it with asbestos or iron strips. After the necessary calculations, the bearing is assembled in the following sequence.

In layout No 1 (Figure 5), the bearing is assembled without intermediate rings, and the dimension AE of the inner rings is measured. This should be no greater than the maximum dimension indicated in the blueprint, minus the maximum clearance, and no less than the minimum dimension, minus the minimum clearance. Dimension AE of the outer rings should be no greater than the maximum dimension indicated in the blueprint, minus twice the size of the maximum clearance, and no less than the minimum dimension, minus twice the minimum clearance.

After these conditions have been fulfilled, all faces of the rings (except intermediate rings which are stamped after finish grinding of their faces) are stamped by means of an electrograph with the letters shown in layout No 1. In layouts No 2 and No 3, dimensions BD, BC, and CD are measured. The clearance between the faces of the inner rings equals: CC equals CD plus BC minus BD.

After this, the inner intermediate ring must be ground down to a dimension equal to CC, plus the axial clearance of the bearing; that is: C equals CC plus the axial clearance. The thickness of the intermediate outer rings is calculated in the same way in layouts No 4 or No 5, or layouts No 6 or No 7:

BB equals (a plus AC plus CD) minus (AB plus BD) in layout No 4

BB equals (AC plus CD) minus (b plus AB plus BD) in layout No 5

B equals BB plus axial clearance

DD equals (b plus EC plus CB) minus (ED plus DB) in layout No 6

DD equals (EC plus CB) minus (c plus ED plus DB) in layout No 7

D equals DD plus axial clearance

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All measurements were taken at four points on the periphery, and their arithmetical average was taken as the final figure. After assembly and measurement, the bearing undergoes final assembly, a control slip is made out for it, it is fastened with wire, and it is sealed.

Experience in the Use of Bearings

The performance of these bearings in actual use was observed at the Zaporozhstal' Plant. In the process of installing and using support bearings in rolling mills, various design and technological shortcomings were revealed, and measures were taken to eliminate them. Bearings which have already gone out of order show that their durability is insufficient. Since the main reason for bearing failures was breakdown of the rollers, special attention was given to the inspection of rollers. Breakdown of the rollers could have originated from longitudinal fissures forming on their surfaces along the lines of nonmetallic inclusions which were not detected by the magnetic defectoscope.

Heavily loaded bearings made of 12KhN3A steel broke down because the ring or roller centers were not strong enough (12KhN3A steel has insufficient hardenability). Therefore, 20Kh2N4A steel was chosen for all casehardened bearings.

These measures, based on an analysis of every bearing that broke down prematurely, increased the life of large-size antifriction bearings and are now being tested in practice.

Two other factors must be taken into account if the work capacity of bearings is to be increased.

1. A gradual transition must be achieved between rectilinear surfaces and roller faces, that is, at points of maximum stress on the roller, curved fillets must be specially ground.

2. Before mounting a bearing in a heavily loaded stand, it should be run in on a lightly loaded stand so that the rolling surfaces can be worked in properly.

/Appended table and figures follow./

Table I

Weight of Forging (kg)	Rolled Stock Dimension (mm)	Weight of Forging (kg)	Rolled Stock Dimension (mm)
40-60	140	180-240	225
60-75	150	240-350	250
75-90	160	350-420	275
90-130	180	420-600	300
130-180	200	600-1,000	350

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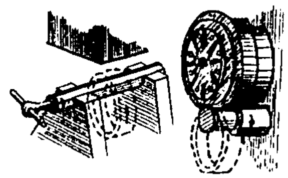

Figure 1. Smith Forging Rings (left) and Hot Rolling Them on Forging Rolls (right)

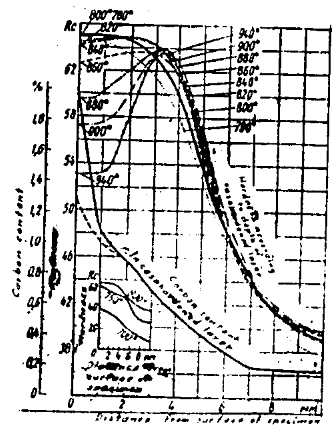

Figure 2. Hardness Curve for 12Kh2N4A Steel, According to the Depth of the Casehardened Layer and Depending on Hardening Temperature.

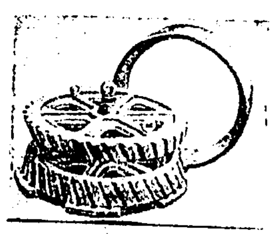

Figure 3. Dies for Hardening Casehardened Tapered Outer Rings

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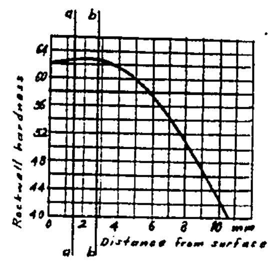

Figure 4. Hardness Diagram, According to the Depth of the Casehardened Layer. Based on Analysis of a Control Specimen; Hardness at Center, 39 on Rockwell C Scale

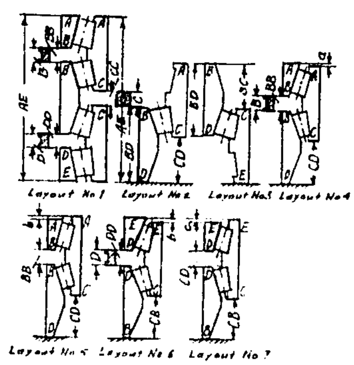

Figure 5. Consecutive Assembly Layouts for Four-Row Roller Bearings

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